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Cobalt Availability—Domestic

A Minerals Availability System Appraisal

By G. R. Peterson, D. I. Bleiwas, and P. R. Thomas

UNITED STATES DEPARTMENT OF THE INTERIOR

Report of Investigations 8848

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UNITED STATES DEPARTMENT OF THE INTERIOR
James G. Watt, Secretary
BUREAU OF MINES

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering the wisest use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to assure that their development is in the best interests of all our people. The Department also has a major responsibility for American Indian reservation communities and for people who live in Island Territories under U.S. administration.

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PREFACE

The Bureau of Minerals Availability Program is assessing the worldwide availability of nonfuel minerals. The program identifies, collects, compiles, and evaluates information on active, developed, and explored mines and deposits, and on mineral processing plants worldwide. Objectives are to classify domestic and foreign resources, to identify by cost evaluation resources that are reserves, and to prepare analyses of mineral availabilities.

This report is part of a continuing series of MAS reports to analyze the supply of minerals from domestic and foreign sources. Analysis of supply from other minerals is currently in progress. Questions about MAS program should be addressed to Director, Division of Minerals Availability, Bureau of Mines, 2401 E Street, N.W., Washington, D.C. 20241.

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COBALT AVAILABILITY–DOMESTIC

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by

G. R. Peterson,[1] D. I. Bleiwas,[2] and P. R. Thomas[3]

ABSTRACT

The Bureau of Mines evaluated the potential supply of cobalt from known domestic resources, both as a primary product from some deposits and as a byproduct from others, and found that U.S. production could play an important role in meeting U.S. cobalt needs by the mid-1980's. This production would be of a relatively short duration, however, with production declining significantly before the year 2000. As part of the study, a tonnage-price relationship was developed indicating the quantity of cobalt that could be produced from known cobalt-bearing deposits at various primary commodity prices and at a 15-percent rate of return on the required capital investment. All capital and operating costs are calculated in August 1980 dollars, and commodity prices are based on August 1980 prices.

Known U.S. cobalt-bearing deposits which represent the current U.S. cobalt reserve base contain some 310,800 metric tons of cobalt in slightly over 1 billion metric tons of demonstrated mineralized material. Approximately 37 percent of the cobalt contained in the reserve base is considered recoverable using existing technology. Of this quantity, some 87,000 metric tons of cobalt is economically recoverable assuming a cobalt price of $25 per pound, a copper price of $1 per pound, and a lead price of $0.40 per pound. Assuming that the cobalt price decreases to $15 per pound, keeping copper and lead prices constant, the quantity that is considered economically recoverable declines to some 45,700 metric tons. Domestic cobalt consumption in 1979 was 7,900 metric tons (17.4 million pounds). Currently, no primary cobalt is produced from domestic resources, and none has been produced since 1971.

INTRODUCTION

Cobalt is a strategic commodity that is a vital element in a modern industrial society. U.S. mine production ceased in 1971, leaving the United

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[2]Geologist.
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States dependent upon imports for its total supply of new cobalt. Moreover, the United States is dependent upon the politically volatile region of southern Africa for most of its imports, primarily Zaire and Zambia.

The sense of urgency concerning assured supplies of cobalt has increased since the sole U.S. distributor of Zairian cobalt, African Metals Corp. of New York, announced in April 1978 that cobalt metal orders after May 1 of that year would be accepted on an allocation basis equivalent to 70 percent of the customer's average monthly purchases during the previous calendar year. Two weeks after the allocation procedure was announced, antigovernment guerrillas invaded the Shaba Province of Zaire, effectively disrupting mining activities in the region. Although the disruption of Zairian supplies of cobalt was of short duration, it underscored the vulnerability of the United States with regard to its supply of such strategic materials.

The purpose of this report is to evaluate potential cobalt production from U.S. sources. Such an evaluation is an inherent element in the formulation of a national mineral policy.

The data collected for this report are stored, retrieved, and analyzed in a computerized component of the Minerals Availability System (MAS). An economic analysis is performed on each deposit to determine its full cost of production at a 15-percent discounted cash flow rate of return (DCFROR). This determines a project's "incentive price" for cobalt; that is, the price at which a firm would be willing to produce cobalt over the long-run, where revenues are sufficient to cover full costs, including a return on investment high enough to attract new capital (1, p. I-25).[4]

Since cobalt primarily occurs as a byproduct or coproduct of copper, nickel, or lead and zinc, a curve can be constructed to show potential cobalt production based upon the "incentive price" to produce the primary commodity concomitant with a curve showing the incremental cost of producing byproduct cobalt. The curves are not supply curves in the traditional sense, since they ignore the parameter of time and are not the industry's marginal cost curve. They are simply an aggregate of total production potential from the industry at a stipulated commodity price that covers full cost of production. Annual curves, as presented in this report, more closely resemble true supply curves since they show production on an annual basis, but they also indicate average total cost rather than marginal cost of production.

For this study, however, because of the relatively small number of U.S. cobalt deposits, most deposit data will be presented in tabular form. A curve has been constructed to indicate the incremental cost of producing byproduct cobalt and nickel from Missouri lead deposits. Curves have also been constructed to illustrate potential annual production from laterite and primary cobalt deposits.

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[4]Underlined numbers in parentheses refer to items in the list of references preceding the appendix.

ACKNOWLEDGMENTS

The authors wish to thank Scott F. Sibley, Cobalt Commodity Specialist, Bureau of Mines Division of Production/Consumption Data Collection and Interpretation, Ferrous Metals Section, for his assistance in determining the properties and associated resource tonnages included in this report, and Daniel S. Witkowsky, Metallurgist, Bureau of Mines Intermountain Field Operations Center, Denver, Colo., for his assistance in analyzing the potential of byproduct cobalt production from Missouri lead mines.

Production and cost data for the deposits analyzed in this study were developed at Bureau of Mines Field Operations Centers in Denver, Colo., Juneau, Alaska, and Spokane, Wash. The Minerals Availability Field Office in Denver performed financial evaluations on the properties and prepared this report.

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CURRENT SOURCES OF COBALT

Structure of the International Cobalt Industry

The international cobalt industry is characterized by two distinguishing features: (1) cobalt is essentially marketed as a byproduct metal in connection with the mining of nickel or copper; (2) the cobalt industry exhibits a high degree of market concentration. Bureau of Mines statistics show that in 1979, some 63 million pounds of cobalt (57 million pounds as cobalt metal) was produced in 11 countries (18, p. 14). The five largest producing countries

(Zaire, Zambia, U.S.S.R., Cuba, and Australia) accounted for 82 percent of world production in 1979. As shown by table 1, Zaire is the dominant country in the international cobalt industry.

TABLE 1. - Shares, by country, of world production of cobalt in 1979

(Percent of world total)

Country	Mining production	Metal production
Zaire	52.6	[1]56.5
Zambia	11.1	10.9
U.S.S.R.	6.4	7.1
Cuba	6.0	-
Australia	5.4	-
Canada	4.8	2.1
Philippines	4.5	-
Finland	4.2	3.1
Morocco	3.2	-
Botswana	.9	-
New Caledonia	.7	-
Japan	-	10.1
France	-	2.8
Norway	-	2.6
United Kingdom	-	1.8
United States	-	1.6
Germany, Federal Republic of	-	1.3

[1]Includes cobalt compound and powder production from Belgium.

NOTE.--Columns do not total exactly 100 percent owing to rounding.

In 1979, Zaire's share of total world refined cobalt metal production was estimated at approximately 57 percent and accounted for some 55 percent of total U.S. imports (including imports from Belgium). Cobalt production from Zaire and Zambia accounted for 67.4 percent of total world production of cobalt metal in 1979.

The degree of concentration of cobalt production by company is also correspondingly high in the Western world. Total cobalt production from Zaire is from the State-owned Générale des Carrières et des Mines (Gécamines). Production from Zambia is accounted for by two government-controlled corporations (51 percent owned by the government), Nchanga Consolidated Copper Mines Ltd. and Roan Consolidated Mines Ltd. Other major producers of cobalt are Western Mining Corp. and Metals Exploration Ltd. of Australia, Outokumpu Oy of Finland (State-owned), Compagnie de Tifnout Tiranimine of Morocco, the French Societe Metallurgique le Nickel in New Caledonia, Marinduque Mining and Industrial Corp. of the Philippines, and Inco Ltd., Falconbridge Nickel Mines Ltd., and Sherritt-Gordon Mines Ltd. of Canada. AMAX is the only U. S. producer, refining mattes supplied from Botswana, New Caledonia, Australia, and South Africa at its refinery in Braithwaite, La.

Foreign Trade in Cobalt

Cobalt is normally processed in the countries where it is mined, and as a result only a small quantity of cobalt is exported in the form of ore (21). Ownership of cobalt resources in producing countries has shifted in recent years from European to local control. European domination was due partly to the history of the industry, which started in the Saxony area, and partly to the colonial arrangement between Belgium and Zaire (formerly the Belgian Congo), where the ore was shipped to Belgium for smelting and transshipped in finished form to world markets. Even today, this historic link between Belgium and Zaire remains strong. The marketing headquarters for Sozacom, the Zairian marketing organization that is the price leader for the cobalt industry, remains in Brussels.

International trade in cobalt is characterized by trading ties that are both regional and historical in nature. Cobalt produced in the Philippines, Australia, and New Caledonia has a natural market in Japan; Moroccan ore output is exported to France; much of Zairian production is still shipped via Belgium to the rest of Europe and the United States; and Cuban nickel-cobalt matte is exported to the U.S.S.R. and to Eastern Europe.

Cobalt producing companies are vertically integrated from mining ore to the metal-producing stage but are not involved in the production of end products. As a result, cobalt is freely traded via the market mechanism.

U.S. Imports of Cobalt From Foreign Sources

The United States depends almost entirely upon imports for its supply of cobalt. Imports constituted 87 percent of U.S. demand in 1978. The remainder came from industry stocks (8 percent) and secondary (scrap) production, which amounted to 5 percent (14, p. 10). Industry stocks and scrap originally came from foreign sources as well, since no primary cobalt is currently produced in the United States from domestic ores. Table 2 shows the sources of U.S. cobalt imports for 1979.

TABLE 2. - U.S. imports for consumption of cobalt, by country, in 1979

Country	Total cobalt content,[1] thousand pounds	Percent
Australia........................	58	0.3
Belgium-Luxembourg[2].............	2,206	11.0
Botswana.........................	358	1.8
Canada...........................	878	4.4
Finland..........................	1,155	5.8
France...........................	537	2.7
Germany, Federal Republic of....	169	.8
Japan............................	675	3.4
Netherlands......................	154	.8
New Caledonia....................	103	.5
Norway...........................	927	4.6
South Africa.....................	139	.7
United Kingdom...................	244	1.2
Zaire............................	8,801	44.0
Zambia...........................	3,538	17.7
Other............................	56	.3
Total......................	19,998	100.0

[1]Includes cobalt content of all forms of imports (for example, metal, oxide, and other forms).
[2]Of Zairian origin.

Source: U.S. Bureau of Mines. Cobalt in March 1980. Mineral Industry Survey, June 5, 1980, p. 5.

The most salient statistic illustrated by table 2 is that Zaire and Zambia (including Zairian cobalt from Belgium) provided 73 percent of U.S. cobalt imports in 1979. However, this U.S. dependence upon imports for cobalt supplies is somewhat counterbalanced by the almost absolute dependence of Zaire and Zambia on mineral-sector exports for foreign exchange revenues. Mineral exports comprised 77.6 percent of total exports from Zaire in 1976 and accounted for 98.7 percent of total exports from Zambia in 1977 (7, pp. 1978, 1815).

The above statistic suggests that, even if hostile regimes assumed power in these countries, it is likely that exports of copper and cobalt to the West would be continued as a matter of economic necessity (nearly 50 percent of cobalt exports from both Zaire and Zambia go to the United States). As a result of this export dependence, future supply disruptions from one of these countries would likely be of relatively short duration, since neither economy could survive a long-term cutoff of export revenues derived from their mining industries.

U.S. Government and Private Industry Stockpiles

The National stockpile was established under the authority of the Strategic and Critical Materials Stock Piling Act of 1946 to ensure a supply of

strategic materials in times of war (3, p. 105). The National Stockpile not only acts as a safeguard for supply in times of emergency but also carries the implicit threat that it could possibly be used as a market mechanism to alter prices. The purchases of cobalt by the U.S. Government can have a significant effect on the market; during the 1950's cobalt purchases by the U.S. Government frequently represented over one-third of world consumption and sales.

The stockpile is now managed by the Federal Emergency Management Agency (FEMA) with a new stockpile objective as of May 1, 1980, of 85.4 million pounds of cobalt (6). The stockpile inventory as of Sept. 30, 1979, was 40.8 million pounds, leaving the stockpile short of its objective by 44.6 million pounds. At the existing level, the stockpile could meet U.S. peacetime consumption for 2.3 years based on reported consumption for 1979 of 17.4 million pounds, while the stockpile at its full complement could satisfy U.S. consumption for 4.9 years.

It is obvious that the stockpile, even at its current level, provides considerable protection against any short-term supply disruption from foreign sources.

The average stocks of cobalt held in private hands during 1979 were 3.4 million pounds, which represented 2.3 months of consumption at the 1979 level. Although not large, these stocks would be sufficient to provide cobalt supplies in the event of short-lived disruptions caused by political upheavals or strikes in producing countries.

CONSUMPTION OF COBALT

Cobalt is used primarily in high-technology fields where materials require high strength; resistance to heat, corrosion, abrasion, and wear; or superior magnetic properties. Some 25 percent of U.S. consumption is processed into nonmetallic compounds. These compounds are used as dryers in paints and in pigments, enamels, rubber, and catalysts. Table 3 illustrates U.S. consumption of cobalt, by end use for the years 1978 and 1979.

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TABLE 3. - U.S. consumption of cobalt in 1978 and 1979, by end use[1]

Use	Contained cobalt, thousand pounds		Percent of total U.S. consumption	
	1978	1979	1978	1979
Steel:				
Stainless and heat-resisting	135	137	0.68	0.79
Full alloy	250	227	1.25	1.30
High-strength low-alloy	12	W	0.06	W
Electric	W	W	W	W
Tool	379	413	1.90	2.37
Superalloys	4,299	5,276	21.50	30.32
Alloys (excludes alloy steels and superalloys):				
Cutting and wear-resistant materials[2]	1,837	2,123	9.19	12.20
Welding materials (structural and hardfacing)	725	444	3.63	2.55
Magnetic alloys	3,768	3,266	18.85	18.77
Nonferrous alloys	590	392	2.95	2.25
Other alloys	378	274	1.89	1.57
Mill products made from metal powder	W	W	W	W
Chemical and ceramic uses:[3]				
Pigments	199	199	1.00	1.14
Catalysts	1,623	1,882	8.12	10.81
Ground coat frit	96	554	.48	3.18
Glass decolorizer	21	43	.11	.25
Other[4]	5	1,791	.03	10.29
Miscellaneous and unspecified	278	381	1.39	2.19
Total	14,595	17,402	73.00	[5]100.00
Salts and dryers: Lacquers, varnishes, paints, ink, pigments, enamels, glazes, feed, electroplating, etc	5,399	[6]NA	27.00	[6]NA
Grand total	19,994	17,402	100.00	[5]100.00

NA Not available.
W Withheld to avoid disclosing company proprietary data; included in "Miscellaneous and unspecified.
[1]Preliminary data.
[2]Cemented and sintered carbides.
[3]Owing to a change in reporting in 1979 from quarterly to monthly, and a change in requested statistics, figures for chemical and ceramic uses are not comparable between 1978 and 1979.
[4]Dryer in paints or related usage plus feed or nutritive additive.
[5]Owing to rounding, column does not total exactly 100 percent.
[6]Included separately as catalysts and other.

Source: U.S. Bureau of Mines. Cobalt in March 1980. Mineral Industry Survey, June 5, 1980, p. 12.

DOMESTIC COBALT RESOURCES AND EXTRACTION TECHNOLOGY

Geology

Cobalt occurs in several distinctive geologic environments. Deposits exist where geologic processes have resulted in cobalt concentrations considerably higher than the average crustal abundance.

The lead and zinc deposits of southeast Missouri occur as replacement of solution collapse structures, replacement of permeable and porous sediments, and mineralization along the uncomformable contact between the Precambrian and the overlying younger sediment. The principal cobalt-bearing mineral associated with these deposits is siegenite, but cobalt is also found in chalcopyrite, sphalerite, galena, and millerite.

The Boss-Bixby deposit of southeastern Missouri is geologically different than the other deposits previously mentioned. The Boss-Bixby is a mineralized diorite intrusive that has been altered to syenite. Mineralization is primarily iron and copper with cobalt. The major cobalt-bearing minerals are covellite and cobaltite.

The Ely Spruce, Minnamax, and Yakobi Island deposits are in basic intrusives. The mineralization is in the form of disseminated sulfide aggregates and inclusions that formed as a result of magmatic segregation during the crystallization process of the intrusive rock. The primary cobalt-bearing minerals include pyrrhotite, pentlandite, and chalcopyrite.

The laterites of the Northwestern United States, primarily in Oregon and Washington, are residues resulting from intense weathering of ultramafic, often serpentized, rock bodies. As the parent rock is weathered, a soil profile develops in which soluble elements are transported downward by meteoric waters. This action causes the leaching of cobalt and nickel once contained in the upper parts of the weathered rock to be transported and precipitated relatively close to the surface, producing a potentially minable resource.

The Blackbird deposit, near Salmon, Idaho, is in a host rock of Precambrian metasediments. This deposit was originally thought to be the result of hydrothermal activity; however, recent work indicates that the deposit may actually be of syngenetic sedimentary origin. The potential ore minerals of Blackbird include cobaltite and chalcopyrite. Anomolous cobalt occurrences in similar stratigraphic sequences up to 50 kilometers from the deposit may indicate that other potential ore bodies exist in the area.

The physical nature and chemical composition of ore dictates the type of technology to separate the desired minerals or elements from the gangue. Some of these process methods are briefly described in the next section.

Technology

Concentrates from sulfide deposits, such as the primary cobalt and copper deposits examined in this study, can be processed using the Sherritt-Gordon

process, which is currently in use at the Sherritt-Gordon Mines refinery at Fort Saskatchewan, Alberta, Canada, for treating nickel-cobalt concentrates. Cobalt and nickel can be recovered from the copper concentrate produced as a byproduct from Missouri lead ores using the Bureau of Mines chalcopyrite upgrade process. The resulting cobalt-nickel concentrate can also be treated using the Sherritt-Gordon process.

Laterite ores may be processed using a reduction roast-ammonia leach process (BMRRL process) developed by the Bureau of Mines Albany (Oreg.) Research Center. This process is currently being tested in a pilot plant operated by the Bureau of Mines and has yet to be developed on a commercial scale.

Extraction of Cobalt From Laterites

Nickel-cobalt laterites are particularly amenable to hydrometallurgical processing methods when cobalt is to be recovered in appreciable quantities. Two basic hydrometallurgical processes are used for laterite ores: (1) reduction roast-ammonia leach, which includes the Caron, UOP, and BMRRL processes, and (2) sulfuric acid leaching.

Reduction Roast-Ammonia Leach Processes

The Caron Process

The original reduction roast-ammonia leach operation was the Freeport Nickel Co. plant in Nicaro, Cuba, which began operation in the mid-1940's. Modified versions of the original process, also called the Caron process, are now active in Greenvale, Australia, and Nonoc Island, Philippines (8, p. 2).

Steps of the Caron process include (1) drying, (2) grinding, (3) selective reduction in multiple-hearth roasters at about 700° to 760° C in a reducing atmosphere, which is usually created using an H_2 and Co gas combination, (4) ammonia carbonate leaching, (5) separation of cobalt, (6) nickel carbonate precipitation and ammonia recovery, and (7) calcination to produce nickel oxide.

The greatest limitation of the Caron process has been low recovery of nickel and cobalt from the saprolite ore fraction. The modified processes used in Australia and the Philippines have enhanced nickel and cobalt recoveries; however, primary nickel recovery remains low (60 to 65 percent) because 9 to 15 percent of the nickel is recovered with the cobalt as a nickel-cobalt sulfide, and further refining is required to separate and recover the nickel and cobalt (15, p. 30).

The UOP Process

The Universal Oil Products Co. (UOP) has developed a modification of the Caron process that uses additives in the reductive roast step with a resultant nickel recovery of over 90 percent from blended limonitic and saprolitic ores. The UOP additives, sulfur and halogen forms, make the ore more amenable to ammonia leaching. However, 9 to 15 percent of the nickel is still recovered

with cobalt, and further refining is required. A 5-ton-per-day pilot plant in Tucson, Ariz., is in full-time operation making test runs on ore from laterites from around the world. Results have been encouraging, especially in the recovery of nickel from saprolite ores.

The BMRRL Process

The Bureau of Mines Albany Research Center has developed a reduction roast-ammoniacal leach (BMRRL) process that incorporates selective reduction in an atmosphere of carbon monoxide and a controlled, oxidizing, ammonia-ammonium sulfate leach with solvent extraction and electrowinning to recover pure (greater than 99 percent) nickel and cobalt. Using this process on domestic laterites, 88 to 92 percent of the contained nickel and 80 to 85 percent of the cobalt are recovered. The BMRRL process entails--

(1) reduction of the metallic oxides in the laterite,

(2) multistage leaching of the reduced material,

(3) solvent extraction from the leach solution,

(4) stripping of the loaded organic solvent to provide a metal-rich electrolyte, and

(5) electrowinning the nickel and cobalt from the stripping solutions.

Advantages of the BMRRL process include the almost complete recovery of nickel and cobalt, recycling of reagents, low energy requirements, and minimal pollution. A 5- to 8-ton-per-day pilot plant has started up.

Sulfuric Acid Leaching

In the sulfuric acid leaching process, such as that used by the Moa Bay Nickel Refinery in Cuba, raw wet ore is slurried and pumped to leaching towers where it is contacted with sulfuric acid at 200° to 250° C to dissolve nickel, cobalt, and magnesium. The solids are separated, and nickel and cobalt are recovered from the solution by hydrogen sulfide precipitation. Operation of the sulfuric acid process is difficult owing to the need for high temperature and pressure operation and is limited because of MgO, Al_2O_3, and iron (Fe) consumption of acid, which limit the ore composition that can be economically treated. If MgO content exceeds 5 percent, high acid consumption generally makes this process uneconomical (12, p. 51). The high magnesia content of domestic laterites precludes the economical use of the sulfuric acid leaching process.

Extraction of Cobalt From Sulfide Ore

The Sherritt-Gordon Process

The Sherritt-Gordon process is a hydrometallurgical process that can be used directly on primary cobalt and copper sulfide concentrates, thus omitting

the smelting stage of processing in most cases. Concentrates with a high arsenic content such as from the Blackbird will require a roasting step. Refining is a pressure-leach with ammonia process that occurs at 70° to 90° C and at 100 to 150 psig in a series of autoclaves. The metals dissolved in the leach solution are then separated out one at a time with copper being the first product recovered. The solution is heated to boil off free ammonia, and a copper sulfide precipitate is formed. The pregnant solution is then treated in an "oxydrolysis" autoclave to convert all unsaturated compounds into ammonium sulfate. Nickel and cobalt are precipitated out of the solution under agitation in an autoclave with an atmosphere of hydrogen at a pressure of 500 psi. The nickel powder is rolled to form nickel strip, and the cobalt is marketed as powder. The remaining ammonium sulfate is recovered by evaporation as ammonium sulfate crystals and is marketed as Sherritt ammonium sulfate fertilizer (4).

Bureau of Mines Chalcopyrite Upgrade Process

Lead ore reserves in Missouri are estimated to contain some 200 million pounds of cobalt and 400 million pounds of nickel. Currently, cobalt and nickel are lost as tailings and slag during the processing stages of lead and copper. However, they could become significant byproducts in the future.

The Bureau of Mines Rolla (Mo.) Research Center has investigated the potential of a chalcopyrite (copper) upgrade process that separates the chalcopyrite concentrate into upgrade chalcopyrite and cobalt-nickel concentrates (20). The process consists of--

(1) closed-circuit grinding of the chalcopyrite concentrate,

(2) adding the flotation reagents diethyl dithiophosphate (collector), sodium cyanide (depressant), and methyl isobutyl carbinol (frother), to the hydroclone discharge and recovering the mixture from the second cleaner cell,

(3) recovering cobalt-nickel concentrate as a sink product from the scavenger cell,

(4) dewatering the cobalt-nickel concentrate slurry from the flotation circuit to a thickener, and

(5) further dewatering the thickener underflow on a rotary vacuum drum filter to a final moisture content of approximately 10 percent and conveying the cobalt-nickel concentrate to a rail car for final shipment to a nickel refinery.

Approximately 81 percent of the cobalt and 83 percent of the nickel entering the cobalt-nickel circuit are recovered in the final concentrate. Net recovery of both nickel and cobalt from the lead ore is around 20 percent.

Recovery of Cobalt From Sea Bed Manganese Nodules

Manganese nodules are found over large areas of the ocean floor at depths of around 900 to 6,000 meters. They range from pea to baseball size and typically contain around 25 to 30 percent manganese, 1.0 to 1.5 percent nickel, 0.5 to 1.0 percent copper, and 0.25 percent cobalt, as well as small quantities of other metals. While all of the oceans contain nodules, the richest concentrations, both in terms of quantity and quality, are found in the central east Pacific area between 0° to 20° north latitude and 120° to 180° west longitude (11, p. 73).

Technologically, the mining of deep-sea manganese nodules is possible using a hydraulic air suction system or a continuous-line bucket system. Much of the prototype equipment has already been designed, patented, built, and tested, although a number of problems remain to be solved (2, p. 66). At this time, the main deterrent to the development of deep-sea resources may not be technological problems but legal problems and international politics.

It is obvious that the major cobalt exporters, such as Zaire and Zambia, view with concern the advent of deep-sea mining for manganese nodules. Even though there may be several hundred million metric tons of cobalt contained in manganese nodules, such occurrences must be considered as little more than a potential resource to be exploited in the future, and therefore they were not considered as a resource within the context of this study.

ESTIMATION OF U.S. COBALT RESOURCE AND COST DATA

The flow of the MAS evaluation process from deposit identification to development of supply information is illustrated in figure 1. This flowsheet

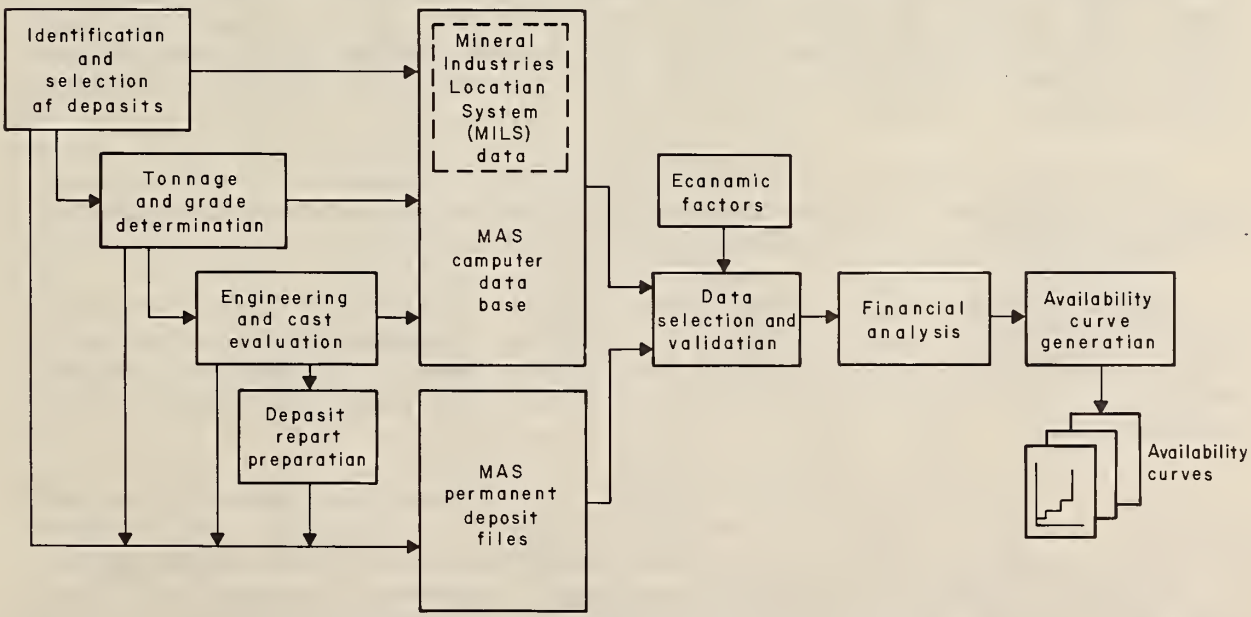

FIGURE 1. - Flow chart of evaluation procedure.

demonstrates the various evaluation stages required to estimate the availability of cobalt.

Twenty-four U.S. mines and deposits were selected for analysis in this study. Selection was limited to known deposits that had demonstrated and/or identified cobalt resources. Using these data, a domestic reserve base was established. The reserve base is defined according to the new mineral resource/reserve classification system developed jointly by the U.S. Geological Survey and the Bureau of Mines (19).

The reserve base is an encompassing resource category delineated by physical and chemical criteria. A major purpose for its recognition and appraisal is to aid in long-range public and commercial planning. For most mineral commodities, different grades and tonnages, or other appropriate resource parameters, can be specified for any given deposit or area, or for the Nation, depending on the specific objective of the estimators; therefore, the position of the lower boundary of the reserve base, which extends into the subeconomic category, is variable depending upon those objectives. The intention is to define a quantity of in-place material, any part of which may become economic depending on the extraction plans and economic assumptions finally used. When those criteria are determined, the initial reserve-base estimate can be divided into three component parts: reserves, marginal reserves, and a remnant of subeconomic resources.

Most of the reserve and resource tonnage and grade calculations presented in this paper have been computed partly from specific measurements, samples, or production data and partly from estimations based on geologic evidence.

Information on the average grades, resource tonnages, and physical characteristics affecting potential production from the deposits was obtained from numerous sources, including Bureau of Mines, U.S. Geological Survey and State publications, professional journals, industry publications, annual reports, company 10K reports and prospectuses filed with the Securities and Exchange Commission, and data made available to the Bureau of Mines by private companies. The knowledge and expertise of Bureau of Mines personnel were utilized in many cases.

Using these reserve and resource estimates, the domestic cobalt reserve base was established. The position of the reserve base within the classification of mineral resources is illustrated in figure 2.

The cobalt reserve base comprises all known U.S. cobalt deposits that have demonstrated resource tonnages and grades. Some deposits, such as the Bornite and Arctic Camp deposits in Alaska, are known to contain significant amounts of cobalt (up to 1 percent), but no actual tonnage and grade data are yet available.

Only 6 of the 24 properties analyzed in this study are currently in production. All six of these are lead-zinc producers in Missouri, none of which is producing cobalt. Although no cobalt has been produced from mines in the United States since 1971, three primary cobalt deposits (the Blackbird, Gasquet, and Madison) were studied with particular interest, since they show the greatest promise of significant production by the mid-1980's (6, p. 224; 10).

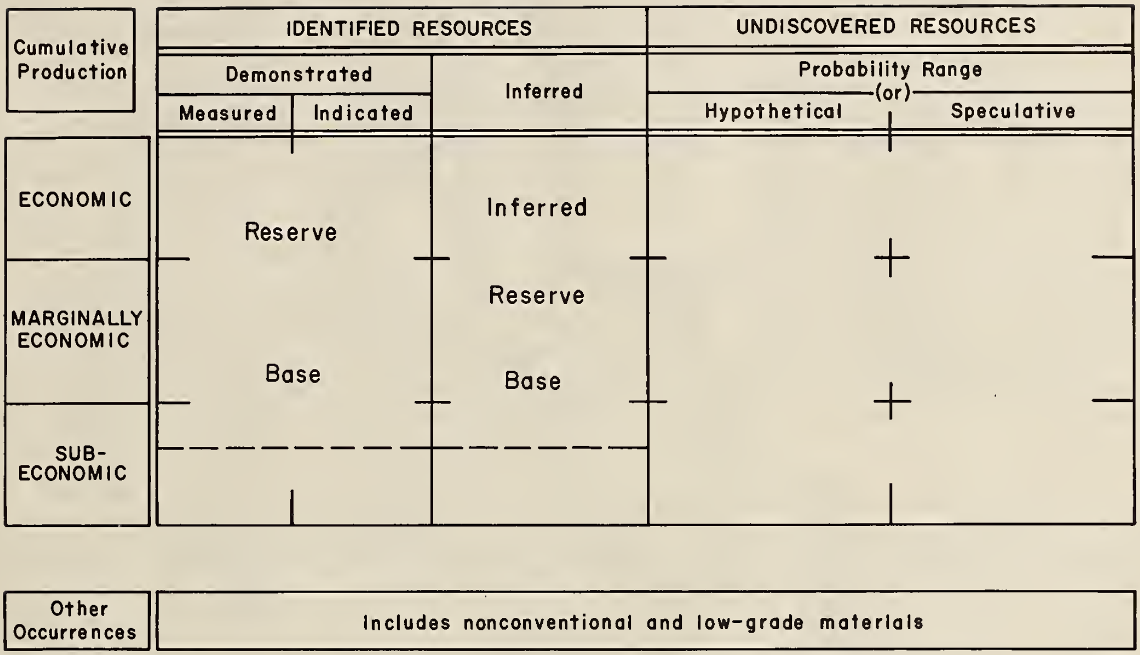

FIGURE 2. - Reserve base and inferred reserve base classification categories (19, p. 5).

After a deposit was identified for analysis, an evaluation of the property was performed at Bureau of Mines Field Operations Centers in Denver, Colo., Juneau, Alaska, and Spokane, Wash. For the producing lead-zinc mines, the designed mining and milling production rates and capacities and other available production specifics were applied in this study. For deposits not in production, appropriate mining, concentrating, smelting and/or refining methods, production rates, and other production parameters were assumed, based upon current engineering principles. A cobalt-nickel concentrate circuit was designed by the Bureau of Mines Rolla Research Center to make possible the recovery of cobalt and nickel, which had previously been lost in tailings during the production of lead, zinc, and copper (13).

Capital expenditures were calculated for exploration, acquisition, development, mine plant and equipment, and for constructing and equipping the mill plant. The capital expenditures for the different mining and processing facilities include the costs of mobile and stationary equipment, construction, engineering, facilities and utilities, and working capital. Environmental costs were included when known. Facilities and utilities (infrastructure) is a broad category that includes the cost of access and haulage facilities, water facilities, power supply, and personnel accommodations. Working capital is a revolving cash fund required for operating expenses such as labor, supplies, taxes, and insurance.

The total operating cost of a mineral project is a combination of direct and indirect costs. Direct operating costs include materials, utilities, direct and maintenance labor, and payroll overhead. Indirect operating costs include technical and clerical labor, administrative costs, facilities maintenance and supplies, and research. Other costs in the analysis are fixed

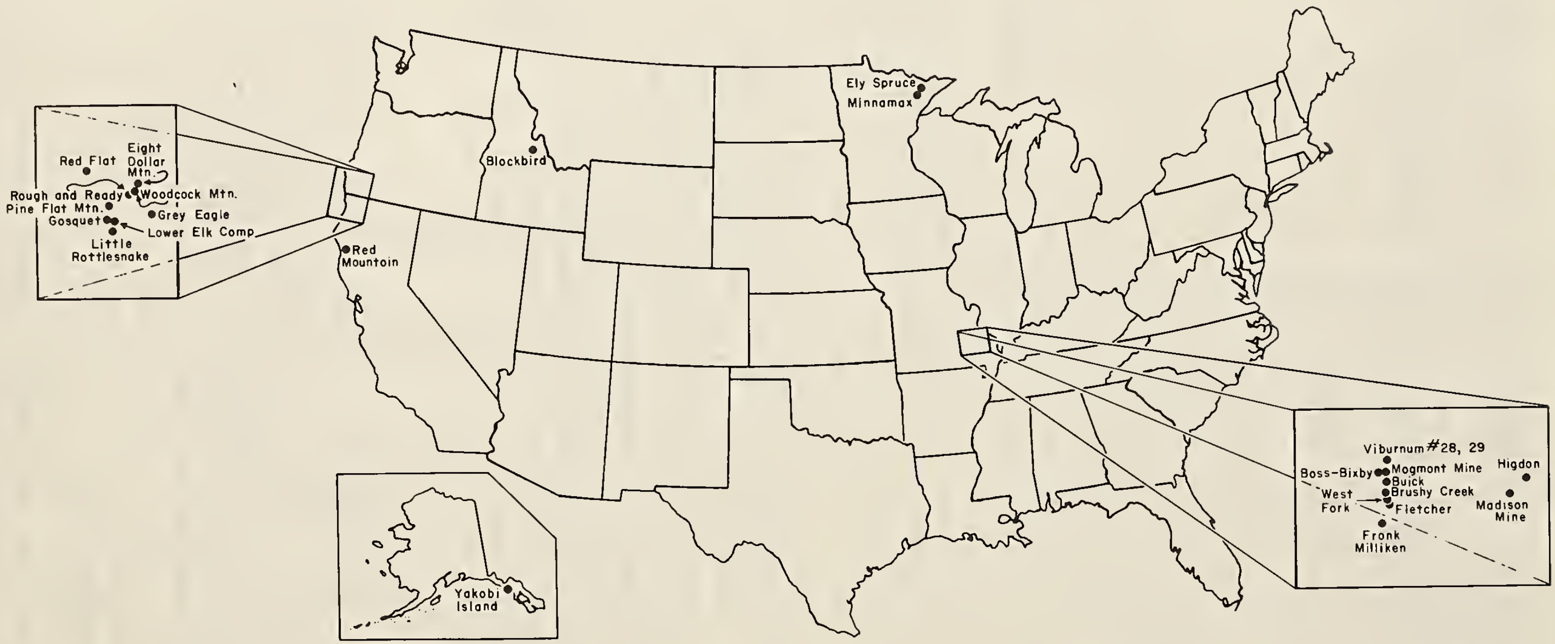

FIGURE 3. - Location of domestic cobalt properties.

charges, including local taxes, insurance, depreciation, deferred expenses, interest payments (if any), and return on investment.

Where available, actual mining capital and operating costs were used. However, because of a lack of cost data available, in many cases costs were either estimated by standardized costing techniques or derived from the Bureau of Mines capital and operaing cost manual (17). Estimates based on this manual have historically shown a reliability within 25 percent of actual costs.

The next step of the evaluation process was to perform a financial evaluation for each property. Using the data developed by the Field Operations Centers, a computerized analysis of each property was performed. For deposits not now in production, all capital costs were converted to August 1980 dollars. For mines currently producing, the undepreciated capital investment remaining in 1980 was calculated. All reinvestment, operating, and transportation costs were converted to August 1980 dollars.

The Bureau of Mines has developed the Supply Analysis Model (SAM) to determine the primary commodity price needed to provide a stipulated rate of return (5). The rate of return used in this study is the discounted cash flow rate of return (DCFROR), which is most commonly defined as the rate of return that makes the present worth of cash flows from an investment equal to the present worth of all after-tax investments (16, p. 232). For this study, a 15-percent DCFROR was considered as a necessary rate of return in order to cover the opportunity cost of capital plus risk.

Individual deposit tonnage-price relationships determined by the SAM were used to construct the tables and resource availability curves presented in this study. The study was conducted in constant August 1980 dollars. No escalation of either costs or prices was included, since it was assumed that any increase in costs would be offset by an increase in prices.

Byproduct and coproduct prices used by the MAS in these economic analyses are shown in table 4. Deposits included in this study are listed in table 5, and the deposit locations are shown in figure 3. Ownership and control data for each property are presented in table A-1 in the appendix.

Tonnage estimates presented in this study are reported in metric tons. For converting from metric tons to short tons, multiply by 1.10231.

TABLE 4. - Commodity prices used in the economic analysis

Commodity	Price, August 1980
Cobalt	$25.000 per pound
Copper	.960 per pound
Iron	85.840 per metric ton
Lead	.420 per pound
Nickel	3.450 per pound
Silver	16.330 per troy ounce
Zinc	.369 per pound

Source: Engineering and Mining Journal and Bureau of Mines Minerals and Materials/A Monthly Survey.

TABLE 5. - Properties comprising the domestic reserve base for cobalt[1]

Property name	Status[2]	Mining[3] method	Primary commodity
Alaska: Yakobi Island............	Exp	OP	Copper-nickel.
California:			
Grey Eagle.......................	Ppd	OP	Copper.
Gasquet..........................	Exp	OP	Nickel-cobalt.
Little Rattlesnake...............	Exp	OP	Do.
Lower Elk Camp...................	Exp	OP	Do.
Pine Flat Mountain...............	Exp	OP	Do.
Red Mountain.....................	Exp	OP	Do.
Idaho: Blackbird Mine............	Dev	OP-UG	Cobalt-copper.
Minnesota:			
Ely Spruce.......................	Exp	OP	Copper-nickel.
Minnamax.........................	Exp	UG	Do.
Missouri:			
Boss-Bixby.......................	Exp	UG	Copper-cobalt-iron.
Brushy Creek.....................	Prd	UG	Lead.
Buick............................	Prd	UG	Lead-zinc.
Fletcher.........................	Prd	UG	Do.
Frank Milliken...................	Prd	UG	Do.
Higdon...........................	Dev	UG	Do.
Madison Mine.....................	Ppd	OP-UG	Cobalt-nickel.
Magmont..........................	Prd	UG	Lead-zinc.
Viburnum #28 and #29.............	Prd	UG	Do.
West Fork........................	Exp	UG	Lead.
Oregon: Eight Dollar Area:			
Eight Dollar Mountain............	Exp	OP	Nickel-cobalt.
Rough and Ready..................	Exp	OP	Do.
Woodcock.........................	Exp	OP	Do.
Red Flat.........................	Exp	OP	Do.

[1]Additional property information is given on table A-1 in the appendix.
[2]Status as of January 1980. Dev--developing mine: Exp--explored deposit: Ppd--past producer: Prd--producing mine.
[3]OP--open pit; UG--underground.

AVAILABILITY OF COBALT FROM DOMESTIC DEPOSITS

General

Cobalt availability was determined at the demonstrated and identified resource levels for each deposit. Resource tonnages, by deposit type, at these levels are presented in table 6.

TABLE 6. -Cobalt resource tonnages by deposit type

Deposit type	Resources, thousand metric tons			
	Demonstrated[1]		Identified[2]	
	In-place material	Contained cobalt metal	In-place material	Contained cobalt metal
Primary cobalt........	13,500	58.9	13,500	58.9
Nickel-cobalt laterites............	56,400	47.0	141,400	112.7
Primary copper........	644,900	150.2	648,500	153.1
Primary lead..........	304,100	54.7	346,400	60.7
Total............	1,018,900	310.8	1,149,800	385.4

[1]Reserve base (measured plus indicated) tonnage.
[2]Measured plus indicated plus inferred resources.

The reserve base, established to estimate cobalt reserves and resources, is that portion of demonstrated resources that has a probability of economic availability (19). It was derived by multiplying the in-place tonnage of each deposit by its in-place cobalt grade. For 1980, the domestic cobalt reserve base was estimated to be 310,800 metric tons of contained cobalt (685 million pounds). Of this amount, 115,700 metric tons (255 million pounds) is estimated to be recoverable. This total comprises all cobalt recoverable from primary cobalt deposits, laterites, and from cobalt-bearing copper and lead deposits. Adding potentially recoverable cobalt from all identified resources, which is the reserve base plus the inferred reserve base, increases the total to 173,500 metric tons (383 million pounds). Cobalt contained in mine or mill tailings, except for the Madison deposit, was not included in the domestic reserve base due to lack of information on tonnages and grades of cobalt contained in tailings. The quantity recoverable at various prices for primary products can be determined by analyzing the tables presented in this section.

This study is a static analysis based on current reserve base estimates and proven and experimental technology. However, as exploration and development yield additional knowledge of grades and tonnages, portions of the material may be reclassified. Historically, domestic resources that can be produced economically have increased because of exploration and technologic improvements that enable the mining of lower grade materials or the processing of materials previously considered waste. Furthermore, changes in economic conditions have a direct impact upon whether a resource is classified as an economic reserve or as subeconomic. A byproduct can also be reclassified to a coproduct or vice versa owing to changes in relative commodity prices.

One function of the MAS is to determine the commodity price necessary to produce a specified level of output from a mineral deposit. An engineering cost study was performed on each deposit to determine its average total cost (ATC) of production. Normal profit is included in the estimate of ATC and is computed at a 15-percent DCFROR. In order to determine the quantity of cobalt

that could be produced on an annual and cumulative basis over the life of each deposit and the cost of this production, the following assumptions have been made:

1. Development of each deposit began in 1980.

2. Each operation can produce at full operating capacity throughout the life of the mining operation.

3. Each operation will be able to sell all of its output at the cobalt price required to receive the desired 15-percent rate of return.

The assumptions used for this study were based upon the desire to determine potential availability of domestic cobalt under an emergency situation. As a result, time lags involved in filing environmental impact statements, receiving necessary permits, financing, etc., are not included in the analysis. Under existing laws and regulations, production from some deposits included in this study may be limited by environmental, political, legal, or other constraints.

Not all the cobalt contained in an ore body will actually be recovered. Some ore may not be recoverable because of the mining method used. Other losses occur as the ore is processed through the concentrating, smelting, and/or refining stages. Recoveries vary widely from operation to operation. A cobalt-nickel circuit at a lead operation in Missouri may recover 20 percent or less of the contained cobalt, while an operation producing cobalt from laterites could recover as much as 85 percent of the contained metal. Based on the results of this study, approximately 37 percent of the domestic cobalt reserve base is recoverable using proven and experimental technologies.

Since cobalt, in this study, could be a byproduct of both lead and copper production, as well as a primary product in other sulfide properties and in laterites, it was not possible to graphically illustrate total available cobalt from all types of deposits on a single resource availability curve. The data are presented in tabular form with a separate table for each type of deposit, and on a curve for the Missouri lead deposits. The curve illustrates the amount of cobalt potentially available as a byproduct of lead production based upon the incremental cost of producing cobalt from the lead deposits. Curves illustrating annual production potential from laterites and primary cobalt deposits are presented at the identified resource level.

Total Recoverable Cobalt

Analysis presented in this section indicates that at an average copper price of $1 per pound, a lead price of $0.40 per pound, and a cobalt price of $25 per pound, the recoverable tonnage of cobalt is 87,000 metric tons (134,400 metric tons at the identified resource level). At these prices, 15 of the properties studied could produce cobalt and earn a 15-percent rate of return. At an assumed cobalt price of $15 per pound, the recoverable cobalt tonnage declines to 45,700 metric tons (83,800 metric tons at the identified resource level).

Laterites and Primary Cobalt Deposits[5]

The total quantity of cobalt recoverable from laterite deposits and two deposits (the Blackbird and Madison) where cobalt is considered the primary product is shown in table 7. The data are presented at various cobalt prices with a rate of return of 15 percent.

TABLE 7. - Potential cobalt production from primary sources at various cobalt prices and a 15-percent rate of return[1]

Cobalt price,[2] dollars per pound	Potential production, metric tons	Cumulative, metric tons
Less than 10.00.........	15,800	15,800
10.00-15.00.............	13,100	28,900
15.01-25.00.............	39,900	68,800
25.01-40.00.............	3,900	72,700
More than 40.00.........	7,400	80,100

[1]Includes laterites and other deposits (Blackbird and Madison) where cobalt is the primary product. Tonnage based on the demonstrated resource level.
[2]Price equals average total cost. Includes byproduct credits.

At the August 1980 cobalt price of $25 per pound, 68,800 metric tons (152 million pounds) of cobalt is potentially recoverable from these sources. At the identified resource level, this figure would increase to 114,400 metric tons (252 million pounds).

Primary Copper Deposits

Five deposits examined in this study, none of which is yet in production, contain copper as the primary commodity. Table 8 shows the total amount of cobalt that is potentially recoverable as a byproduct of these deposits.

TABLE 8. - Potential cobalt production from copper deposits at various copper prices and at a 15-percent rate of return

Copper price,[1] cents per pound	Potential cobalt production,[2] metric tons	Cumulative, metric tons
Less than 100................	11,100	11,100
101-125......................	2,300	13,400
126-150......................	12,600	26,000
More than 150................	2,500	28,500

[1]Price equals average total cost. Includes byproduct credits.
[2]At the demonstrated resource level.

[5]In laterite deposits, cobalt can be the primary product, a coproduct with nickel, or a byproduct of nickel production depending upon the relative grades and prices. For this study, price determinations were performed only for cobalt using nickel as a byproduct.

Since cobalt is a byproduct, no production of cobalt is possible without the prior decision to produce copper from these deposits. As a result, the potential recovery of cobalt from these deposits is dependent upon the price and production of copper. Based upon the August 1980 copper price of $0.96 per pound, table 8 shows that 11,100 metric tons of byproduct cobalt is potentially recoverable at current copper prices. However, in the case of one deposit, the copper ore body is overlain by another ore body containing gold and silver that would be mined before the copper ore body is accessible.

A copper price of $1.50 would be required to enable the recovery of 26,000 metric tons of cobalt, and a copper price of more than $2 would be required to enable the potential recovery of the 28,500 metric tons of cobalt contained in these deposits.

Primary Lead Deposits

Since cobalt would be produced from Missouri lead mines only as a byproduct of lead production, the price for lead, not for cobalt, is the determining factor. Of the eight Missouri lead deposits analyzed in this study, six are currently producing lead, but none is recovering cobalt and nickel. Based on the August 1980 lead price of $0.42 per pound, it appears that all eight could economically produce cobalt as well as lead. However, such production would require addition of a chalcopyrite upgrade circuit as well as added smelter and/or refinery toll charges.

Currently in the six producing Missouri lead mines cobalt and nickel are lost as tailings and slag during the processing stages of lead and copper. To recover cobalt and nickel from these deposits, a chalcopyrite upgrade circuit must be added that separates the chalcopyrite (copper) concentrate into upgraded chalcopyrite and cobalt-nickel concentrates (20).

The additonal (incremental) cost of recovering cobalt and nickel from producing lead mines has been calculated, including the cost of building the chalcopyrite upgrade circuit in the mill and the additional smelter/refinery toll charges. Based on these costs, a total of 7,100 metric tons of byproduct cobalt is potentially available from Missouri lead deposits, as shown in table 9 and figure 4.

TABLE 9. - Potential cobalt production from Missouri lead deposits at various cobalt prices [1]

Cobalt price,[2] dollars per pound	Potential production[3] metric tons	Cumulative metric tons
Less than 10.00.................	2,900	2,900
10.00-12.00.....................	1,000	3,900
12.01-14.00.....................	1,800	5,700
14.01-16.00.....................	0	5,700
16.01-19.00.....................	1,200	6,900
19.01-22.00.....................	200	7,100

[1] Cobalt price is based on the incremental cost of production of cobalt, which includes the additional investment for the cobalt-nickel circuit and the additional smelter and/or refinery charges for cobalt recovery. Includes a 15-percent rate of return on invested capital.
[2] Price equals average total cost. Includes by product credit for nickel.
[3] Assumes a lead price of $0.42 per pound.

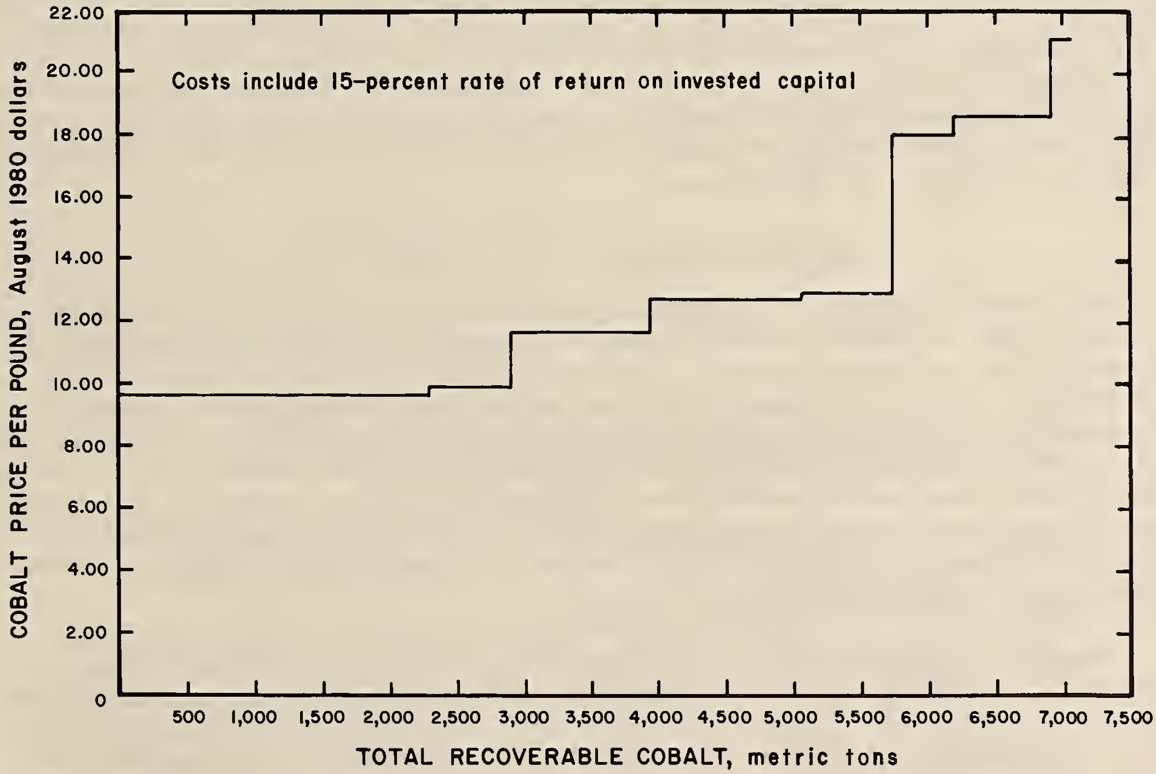

FIGURE 4. - Potential production of cobalt from Missouri lead deposits based on the incremental cost of cobalt recovery at various cobalt prices. Price includes byproduct credit for nickel.

Recovery of cobalt from lead mines is dependent upon three factors:

1. Lead production is a preprequisite for the production of byproduct cobalt.

2. Cobalt prices must be high enough to justify the incremental cost of extraction.

3. A market must exist for the cobalt-nickel concentrate that could be produced.

At current prices, for both lead and cobalt, all the cobalt potentially available as a byproduct of Missouri lead production appears to be economic. Owing to disequilibrium in the international cobalt market, the average annual cobalt price has risen dramatically from $5.58 per pound in 1977 to the price in 1980 of $25 per pound. However, there is no certainty that cobalt prices will remain at such a level in the future, and it is possible that the price may fall to as low as $15 per pound during 1981 (9). It is likely that mine operators are waiting to see if cobalt prices will remain firm over a longer period of time before making the investment decisions. Uncertainty also stems from possible problems marketing the cobalt-nickel concentrate to existing nickel refineries. Although Sherritt-Gordon has expressed interest in such concentrates for refining in their Fort Saskatchewan, Alberta, refinery, and there is a possibility that Anschutz would be able to refine Missouri cobalt-nickel concentrates upon completion of their planned Madison Mine operation, nothing is definite at this time.

Potential Annual Cobalt Production

Of primary concern to Government policymakers is not only the question of how much total recoverable cobalt exists domestically, but also how much is recoverable on an annual basis. When performing the engineering analysis on each deposit, Bureau of Mines personnel determined a development schedule for each deposit. The time required to develop each deposit varies owing to such factors as the relative location of the deposit and the necessity for further exploration, development, and plant construction. Also, depth of overburden, type of mining method employed, and amount of infrastructure required to develop the deposit are significant factors influencing the time lag between initial development and startup.

Domestic consumption of cobalt has been forecast to increase from 7,900 metric tons (17 million pounds) in 1979, to 11,900 metric tons (26 million pounds) by 1985 (14, p. 18). U.S. cobalt production could potentially satisfy a significant percentage of total U.S. consumption during the mid-1980's. However, the analyses indicate that this production potential is of short duration, with production declining during the 1990's.

Potential annual cobalt production in selected years from laterites and primary cobalt deposits is shown in table 10. This is illustrated at the identified resource level in figure 5. Potential annual production as a byproduct of copper is shown in table 11, and production as a byproduct of lead based upon the incremental cost of producing cobalt is shown in table 12.

TABLE 10. - Potential annual cobalt production from laterites and primary cobalt deposits in selected years at various cobalt prices and a 15-percent rate of return[1]

Cobalt price,[2] dollars per pound	Recoverable cobalt per year,[3] metric tons				
	1981	1984-87	1990	1995	2000
Under 12.00................	0	1,200	1,200	900	0
12.01-15.00................	0	2,000	800	0	0
15.01-19.00................	0	1,000	300	0	0
19.01-23.00................	0	2,700	2,700	0	0
Total.................	0	6,900	5,000	900	0

[1] Includes laterites and other deposits (Blackbird and Madison) where cobalt is the primary product.
[2] Includes byproduct credits.
[3] At the demonstrated resource level.

TABLE 11. - Potential annual cobalt production from copper deposits in selected years at various copper prices and a 15-percent rate of return

Copper price,[1] cents per pound	Potential cobalt production per year,[2] metric tons			
	1983	1985	1987	1989-2000
Less than 100...........................	400	400	400	600
101-125.................................	100	100	100	100
126-150.................................	0	200	300	300
More than 150...........................	0	100	100	100
Total.............................	500	800	900	1,100

[1] Price equals average total cost. Includes byproduct credits.
[2] At the demonstrated resource level.

TABLE 12. - Potential annual cobalt production from Missouri lead deposits in selected years at various cobalt prices and a 15-percent rate of return[1]

Cobalt price,[2] dollars per pound	Recoverable cobalt per year,[3] metric tons			
	1981	1983-1994	1995	2000
Less than 10.00................	100	100	100	100
10.01-13.00....................	100	100	100	100
13.01-16.00....................	0	0	0	0
16.01-23.00....................	0	100	0	0
Total.....................	200	300	200	200

[1] Assumes a lead price of $0.42 per pound.
[2] Cobalt price based on the incremental cost of production of cobalt, which includes the additional investment for the cobalt-nickel circuit and the additional smelter and/or refinery charges for cobalt recovery. Price equals average cost and includes byproduct credit for nickel.
[3] At the demonstrated resource level.

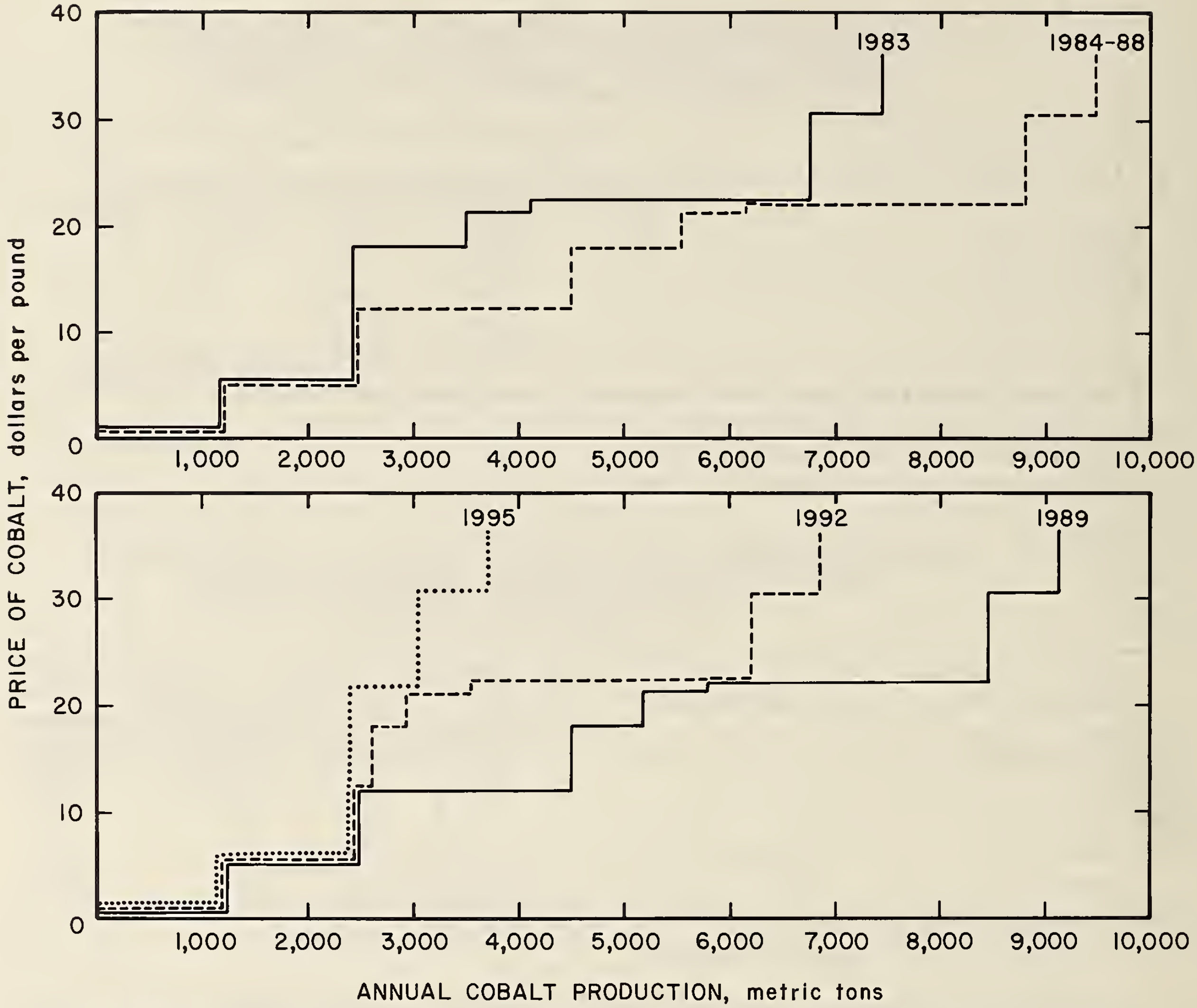

FIGURE 5. - Potential annual cobalt production in selected years from laterites and primary deposits (at the identified resource level).

These annual resource availability curves and tables indicate significant cobalt production potential beginning in 1983 and increasing each year until 1985. Production would remain relatively constant until 1992 and then begin to decline. This decline reflects the static nature of this study and should not be construed as indicating resource exhaustion, since it is likely that new deposits would be discovered and cobalt recovery methods improved in the interim.

In summary, assuming an average copper price of $1 per pound, a lead price of $0.40 per pound, and a cobalt price of $25 per pound, the potential production of cobalt in 1985 is 7,600 metric tons (17 million pounds). At the identified resource level, the potential production figure increases to 9,400 metric tons (21 million pounds). At an assumed cobalt price of $15 per pound, the economically recoverable quantity in 1985 declines to 3,900 metric

tons (9 million pounds) or to 5,100 metric tons (11 million pounds) at the identified resource level.

CONCLUSIONS

This study indicates that a significant percentage of U.S. cobalt consumption could be supplied by known U.S. sources, although this production would be of relatively short duration.

Twenty-four cobalt-bearing deposits have been analyzed to determine the quantity of cobalt available from each deposit and the prices of the various primary products required to provide each operation with a 15-percent rate of return. The 1980 cobalt reserve base is 310,800 metric tons of contained cobalt. Of this amount, an estimated 115,700 metric tons (255 million pounds) of cobalt is recoverable. Including potentially recoverable cobalt from all identified resources, the recoverable tonnage increases to 174,300 metric tons (384 million pounds).

Based upon the results of this study, U.S. cobalt producers could contribute significantly towards satisfying domestic consumption for cobalt in the United States during the 1980's. The three deposits most likely to be developed in the near future (Blackbird, Madison, and Gasquet) are capable of producing a total of some 4,900 metric tons of cobalt per year by 1985 based upon the economic conditions existing at the time of this study. This amount would be the equivalent of 41 percent of estimated U.S. demand for 1985. However, unless additional supplies of cobalt are discovered and brought into production, U.S. production would provide only short-term relief from the Nation's dependence on imports and will not significantly alter the structure of dependence over the long-run.

The United States maintains a strategic stockpile of cobalt that serves as a buffer against possible future disruptions of cobalt supplies. The potential production of cobalt estimated in this study could further insulate the United States from vulnerability from external factors and would provide time for future U.S. discoveries of cobalt and the possible development of an ocean-mining industry.

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APPENDIX

TABLE A-1. - Ownership and control of domestic cobalt properties

State/mine name	Domain	Type of mineral holding	Owner/operator	Status	Percentage of ownership
Alaska: Yakobi Island	National forest.	Located claim	Inspiration Devel. Co.	Owner-operator	100
California:					
Grey Eagle	Unknown.	Patented--located claim.	1. Siskon Corp.	Owner	100
			2. Noranda	Operator	0
Gasquet	National forest.	Located claim	California Nickel Corp.	Owner	100
Pine Flat Mountain	...do...	.....do	Hanna Mining Co.	.....do	100
Little Rattlesnake	...do...	.....do	Del Norte Mining Co.	.....do	100
Lower Elk Camp	...do...	.....do	California Nickel Corp.	.....do	100
Red Mountain	...do...	Located claim--private lease--fee ownership.	Hanna Mining Co.	.....do	100
Idaho: Blackbird Mine	Private.	Patented	1. Hanna Mining Co.	Owner	100
			2. Noranda Exploration Inc.	Operator	0
Minnesota:					
Ely Spruce	National forest.	Private lease--Federal lease--fee ownership.	International Nickel Co.	Owner-operator	100
Minnamax	...do...	State lease--private lease--Federal lease.	Amax Exploration Inc.	.....do	100
Missouri:					
Higdon	Mixed...	Private lease--Federal lease--fee ownership.	Bunker Hill Mining Co.	Owner	100
Boss-Bixby	...do...	Federal lease--fee ownership.	1. Getty Oil Co.	.....do	51
			2. Azcon Corp.	.....do	24
			3. Hanna Mining Co.	.....do	24
Viburnum #28 and #29	National forest.	Federal lease--private lease-fee ownership.	St. Joe Minerals Corp.	Owner-operator	100
Buick	Mixed...	Federal lease--fee ownership--minerals only.	1. Amax Lead Co. Missouri	Owner	50
			2. Homestake Lead Co. of Mo.	.....do	50
			3. Amax	Operator	0

Missouri--Continued					
Magmont............	Mixed...	Federal lease--private lease-fee ownership.	1. Cominco American Inc.....	Owner-operator	50
			2. Dresser Minerals.........	Owner.........	50
Madison Mine-OP/UG..	Unknown.	Private lease..........	Anschutz Uranium Corp.......	.....do.......	100
Fletcher Division...	Mixed...	Federal lease--private lease.	St. Joe Minerals Corp.......	Owner-operator	100
Brushy Creek........	...do...	.....do................	.....do....................	.....do.......	100
West Fork...........	...do...	.....do................	ASARCO.....................	Owner.........	100
Frank Milliken......	...do...	Private lease--fee ownership--minerals only.	Kennecott (Ozark Lead)......	Owner-operator	100
Oregon:					
Red Flat............	Mixed...	Located claim..........	1. Hanna Mining Co..........	Owner-operator	28
			2. Red Flats Nickel.........	Owner.........	59
			3. Big Basin Nickel.........	.....do.......	13
Eight Dollar Mountain.	...do...	Located claim--private lease.	Numerous miscellaneous owners.	.....do.......	NA
Woodcock............	...do...	Located claim..........	1. Hanna Mining Co..........	.....do.......	80
			2. Inspiration Develop. Co..	.....do.......	15
			3. California Nickel Corp...	.....do.......	5
Rough and Ready.....	...do...	Located claim--private lease.	1. Inspiration Devel. Co....	.....do.......	95
			2. Walt Freeman............	.....do.......	5

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